II. — *Remarks on the Water Supply of Ancient Rome.*

By Professor M. H. MORGAN,
HARVARD UNIVERSITY.

The Commissioner of Water Supply of the City of New York, in his report for the year 1900, remarked that the question of "public water supply transcends every other subject and object of municipal government in importance and in immediate effect on every human being of whatever condition of life." Whether the Commissioner was aware that he was merely amplifying the Pindaric *ἄριστον μὲν ὕδωρ* may be matter for doubt; not so the truth which he expressed, for with it everybody will agree. What is true now of the life of a modern municipality in so fundamental a concern must in great part have been true of the life of an ancient municipality, and therefore it behooves all students of ancient Roman life to consider what can be learned of the water supply of ancient Rome. Not to go into this subject in details, I shall at present confine myself to the consideration of the *amount* of public water supply available in Rome down to the end of the first century A.D.

Our authority on this point is of course that honest and painstaking official, Frontinus, who became water commissioner in the year 97 A.D., and who was, to judge from his own writings, the model of what a public official ought to be. Justly, therefore, he has been compared to the late Colonel Waring by Professor Bennett, in a recent excursion from the somewhat arid, though still, I think, potential plains of syntax into the definiteness of an article in the *Atlantic*. But Professor Bennett is not the only American who has written on Frontinus. Mr. Clemens Herschel, a well-known hydraulic engineer, published two years ago a volume invaluable for our topic. It contains a facsimile of the manuscript of Frontinus on the Aqueducts of Rome (here published for the first time), an excellent English translation, and an explana-

tory commentary written from the point of view of the modern engineer. Both classical scholars and practical engineers owe a debt of gratitude to Mr. Herschel, who is, I believe, the only one of his fraternity who has shown during the last hundred years an intelligent interest in the ancient history of his profession.

In the course of his book Mr. Herschel endeavors to make a conservative estimate of the amount of water supplied daily to the Romans by the nine aqueducts, the last of which was completed in 52 A.D. It would indeed be very interesting if we could learn this amount, so that we could compare the water supply of ancient Rome with that of our own great cities. But unfortunately it is, I think, impossible to arrive at any figures which shall even approximate to exactness. This statement is entirely at odds with those which are to be found in modern handbooks on antiquities. For example, in Smith's *Dictionary of Greek and Roman Antiquities* (I, p. 150), we are told that the supply amounted to 332 million gallons a day; in Middleton's *Remains of Ancient Rome* (II, p. 349), to about 340 million; in Lanciani's *Ruins and Excavations of Rome* (p. 58), to about 423 million; and these are fair samples of the figures which are given in the French and German books. Now, what would such supplies amount to *per capita* (to use the term of modern water reports) of the population? We cannot be certain about the number of inhabitants of ancient Rome; but if we accept the estimate of a million for the time of Augustus, we should have from about 330 to 420 gallons a day as the per capita rate; or, if we suppose that the population had grown to a million and a half by Vespasian's time,[1] we should have a per capita rate of from 220 to 280 gallons a day. As either of these estimates gives a much greater allowance than that made by any modern system of water supply, the books regularly go on to explain that this large allowance was made necessary by the constantly running public fountains, the

[1] For the various theories and estimates, with references to the literature of the subject, see Friedlaender, *Sittengeschichte Roms*, I[6], pp. 58–70.

private fountains, the great public pools and baths, the provision for sham naval fights, etc. But I am inclined to think, on *a priori* grounds, that the requirements of ancient Rome were not greater than those of a modern metropolis — perhaps even not so great. Consider, for instance, our hotels and apartment houses, great and small — in how many different public rooms, including lavatories and *latrinae*, is water constantly running. And so in the great business blocks and public buildings. The running water in all these is to be compared with that in the public fountains of Rome; for our public fountains are still comparatively few, although the number is larger now than formerly. Consider also the water used for street sprinkling, for mechanical and manufacturing purposes, by railroad, gas, and electric light companies, breweries and sugar refineries, etc. Many new industries unknown to Rome are gathered in our cities, and the old industries are still going on under higher developments. I find, therefore, no defence in the supposed larger requirements of ancient Rome for the enormous per capita rate which the statements in the handbooks imply. And so on this ground alone I should doubt these statements.

Mr. Herschel also doubts them, but on other grounds. He points out that they must necessarily be based on the figures found in Frontinus, who gives the water supply of each aqueduct in *quinariae*. But the *quinaria* is a variable unit and therefore absolutely unscientific. It shows us nothing about the *volume*, for it is merely the measure of the area of a cross section of water in a pipe of a certain arbitrary size (known to us, but not necessary to specify here). As Mr. Herschel remarks, the volume cannot thus be measured; for it depends not only on the size of the pipe but on the velocity of the current moving in it; and this in turn on the answer to the question whether the water is discharged into free air, into still water, or into flowing water. It depends also upon the "head," that is, upon the depth of the basin from which it is drawn, and likewise upon the length of the pipe itself and its declivity. Now all these are points which Frontinus altogether ignores, if indeed in his day he could

have had any but the vaguest ideas about the causes and effects of the velocity of a stream in a pipe. And further, he uses his unit *quinaria* of the same pipe both at its intake and its delivery, although the velocity was presumably not the same at these two points. Obviously it is impossible to reach any exact figures about volume from such data as he gives.

Whence come then the figures given in our handbooks? They appear to be based, as Mr. Herschel remarks, upon a calculation put forth very cautiously by a French *savant*, De Prony, in 1817.[1] He tried to find the value of the *quinaria* by comparing it with the unit employed in Rome in his own day, and reached the conclusion that it was about 56 cubic metres, or 15,000 gallons (American) in 24 hours. Now as the total number of *quinariae* delivered every day by the nine aqueducts was, according to Frontinus, 14,018, this would give about 200 million gallons as the daily supply of ancient Rome. But De Prony deliberately based his estimate on two assumptions: first, assuming that the head acting on the *quinaria* was equal to its length; secondly, assuming that the *quinaria* was discharging into free air. But neither of these assumptions have we the right to make — certainly not the latter, for the *quinariae* did not discharge into free air, but out of the delivery tanks into the pipes that ran to buildings, fountains, etc. Still, De Prony's principle has been adopted and his figures in details amplified until we get in our books the vast number which I have cited.

Observing these fallacies, Mr. Herschel has tried to get a better idea of the amount of Roman water supply from some more recent investigations made by Colonel Blumenstihl, an engineer.[2] His method was as follows: he measured the actual velocity of the Aqua Marcia at the present time at a point near its intake, and found it to be $3\frac{1}{4}$ feet per second.

[1] *Mém. de l'Institut: Acad. des Sciences, Math., et Phys.*, II, p. 417.

[2] *Brevi Notizie sull' Acqua Pia:* 1872. Lanciani himself approved the method of these investigations in his large Italian work on the aqueducts, *I Commentarii di Frontino*, p. 362.

At about this point Frontinus says that it had 4690 *quinariae.* The proper calculation readily shows that a *quinaria* pipe running at this rate per second was discharging about 9250 gallons. But the term *quinaria* was, as we have seen, used by Frontinus of the amount of water at other points in the aqueduct, — at its point of discharge for instance. The term, therefore, was employed of water flowing with less velocity — for example, at the rate of two feet or even of one foot per second. In other words, as Mr. Herschel remarks, the value of a *quinaria* might range from about 9000 gallons in 24 hours to about 2500 gallons. Taking a liberal average (say 6000 gallons), he calculates that the total of 14,018 *quinariae* delivered daily by the nine aqueducts may have amounted to about 84 million gallons a day. And this amount was, according to Mr. Herschel, the maximum of Roman water supply. He goes on, however, to observe that, according to Frontinus, a good deal of water was either wasted by leakage along the route or diverted by being drawn off illegally by individuals before it reached the distributing points in Rome. But the figures given by Frontinus are exclusive of such wastes and thefts. This is a fact which Mr. Herschel seems not to have observed when he proceeds to reduce his 84 million gallons by more than one-half in order to find the actual supply minus these thefts and leakages.

If, now, we accept the estimate of 84 millions, and suppose that this supplied a million people, we get a per capita rate of 84 gallons a day; or for a million and a half of people, 56 gallons a day. It must be remembered that this estimate is almost purely conjectural, for it depends only upon the actually measured velocity of a single aqueduct near its point of intake. Still, it is obviously more trustworthy than the figures which we find in our handbooks, and it may therefore be compared with the water supplies of several cities in the United States. The figures for these are taken from reports kindly furnished to me, either in print or letter, by the water commissioners of the various cities, and are for the year 1901, except in the case of Chicago, which is for 1900. They represent actual consumption, not possible supply,

which could not be given in all cases. The figures for Rome represent supply. But the discrepancy makes no difference to my argument, for it will be seen that in all but two cases the per capita consumption in the modern cities is greater than the per capita supply of 84 gallons estimated for Rome. The figures are as follows: —

City.	Average daily consumption in gallons.	Per capita consumption in gallons.
Cambridge	7,520,976	80.7
Borough of Brooklyn, N.Y. . .	97,000,000	83
Baltimore	56,000,000	100
Boston	101,492,000	120
Boroughs of Manhattan and The Bronx, N.Y.	275,000,000	134
Chicago	322,599,630	161
Philadelphia	279,975,453	211.9

From these figures we see that in the city of Cambridge[1] and the borough of Brooklyn the per capita consumption is less than the 84 gallons of supply estimated for Rome. In passing we observe that Brooklyn, with a population of 1,166,000 (or about that which is generally estimated for Rome), has a consumption[2] almost exactly equal to Mr. Herschel's estimate of the Roman supply. We note further that the consumption of Boston is nearly one-half as much again as the supply of Rome; the consumption of the boroughs of Manhattan and The Bronx is more than half as much again; the consumption of Chicago is nearly twice as great; and finally the consumption of Philadelphia is more than two and a half times the supply of Rome. If the population of Rome is taken at a million and a half, the excess of per capita rate in favor of modern cities will be vastly greater. Now the result of these comparisons is just what I should,

[1] With a population of 93,000 — the only city on the list having less than half a million people.

[2] The water commissioner, however, reports that the available supply is wholly inadequate for the demand.

on my *a priori* grounds, have expected to reach; namely, that the water supply of ancient Rome was not so great as that which a large city in modern times requires.

We must not forget, however, that this conclusion is based upon *conjectures* about the amount of supply and the number of inhabitants of Rome. But it may also be reached, I believe, without any conjecture at all in an entirely different manner; that is, by showing that the public water supply in modern cities has increased from time to time in greater proportion than the supply of Rome increased. I have drawn up from Frontinus a table which shows the comparative increase of Roman water supply with the building of the different aqueducts. Necessarily it is expressed in *quinariae*, but this does not affect my purpose. The table gives also the dates at which the aqueducts were built.

Aqueduct.	Date.	Supply in *quinariae.*	Total supply.
Appia	312 B.C.	704	704
Anio Vetus	272–269	1610	2314
Marcia	144–140	1935	4249
Tepula	125	445	4694
Julia	33	803	5497
Virgo	19	2504	8001
Alsietina	Augustan	392	8393
Claudia	38–52 A.D.	2812[1]	11,205
Anio Novus . . .	" "	2813[1]	14,018

From this table it appears that it had not been found necessary to double the supply between the time of Cicero, who died in 43 B.C., and the completion of the Claudian and New Anio aqueducts in 52 A.D., a period of 95 years, including the Augustan age with all its grandeur and development. After the building of these two aqueducts it was almost tripled. But take the city of New York. The consumption in 1860 was 54 million gallons; in 1900, after a period of

[1] We know the amount supplied by these two aqueducts together, but not by each singly.

only 40 years, it had become 255 million, or 4.7 times as much. I am careful here to compare only the present borough of Manhattan with what was the old city of New York. In the same period the per capita consumption has doubled. The year 1860 is the earliest for which figures could be furnished to me by the New York Commissioner of Water Supply. For Boston we can go back farther, and it appears that since 1850, in the period of 51 years, the per capita consumption has increased nearly 2.9 times (from 42 gallons to 120). In Baltimore and Philadelphia, in the 50 years from 1852 to 1902, the per capita consumption has increased 7.1 and 6.3 times respectively (from 14 to 100 gallons, and from $33\frac{86}{190}$ to 211.9 gallons). Chicago (but this is of course a most peculiar case) had in 1854 a per capita consumption of 8.9 gallons, which had risen in 1900 to 161 gallons. During the last thirty years it has increased 2.2 times.

It appears, therefore, that we cannot trust our books on antiquities, and that until other evidence is produced we should believe that the Roman uses for water, and consequently the water supply, were less than those of a modern metropolis.